

# Assessment of a Solar Cell Panel Spatial Arrangement Influence on Electricity Generation

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**Abstract.** The research evaluates the impact of the spatial arrangement of solar cell panels on the amount of electricity generated (power generated by solar cell panel) in Tyumen. Dependences of the power generated by the solar panel on the time of day, air temperature, weather conditions and the spatial arrangement are studied. Formulas for the calculation of the solar cell panel inclination angle which provides electricity to urban infrastructure are offered. Based on the data in the future, changing of inclination angle of solar cell panel will be confirmed experimentally during the year in Tyumen, and recommendations for installing solar cell panels in urban infrastructure will be developed.

## 1. Introduction

At the present time technological and technical development level of fuel and energy production determines the structure of consumed energy resources, its environmental and development trends [1,2,3]. Technical development of industrial branches depends on the climatic conditions of the regions such as air temperature, solar radiation, barometric pressure and humidity [4,5,6,7,8,9,10,11,12,13]. We need to explore renewable, alternative and clean sources, as traditional forms of energy reserves are shrinking [14]. This trend of development is presented in the researches, which describe the use of stand-alone traffic lights, replacement of traditional forms of energy sources and so on [15,16].

In the modern world the proportion of energy that we get from alternative sources is 9.3%. The main part of it is made by means of hydroelectric power plants. It is 6.8%. The energy that we get from the sun is 0.33%. However, in 2050 the proportion of energy that we will get from solar power plants will exceed consumption of other types of fuel and the share of consumption will be 27% [17,18]. These data are presented in the International Energy Agency report. The development of solar energy industry is described by the cycle time of 6-7 years. The first leader in the development of solar energy industry was Japan. At the present time it is China.

In the Russian Federation, the development of solar energy began in 2013-2014. Now its share is 0.2%, which it is low in world production. At the present time in Russia, there are 23 solar power plants, which have a total capacity of 634 MW [19]. The development of solar energy industry depends on many factors, in particular, it is power plant geographical location [20].



The sun is "ecologically clean" source of energy, which is inexhaustible. It is one of these energy advantages that distinguish it from oil gas and other fuels. However, the disadvantages of solar energy industry are produced energy dependence on climatic conditions and time of day, also high investments and large occupied territory.

Solar radiation is converted into electric power by solar cell panels. Its advantages are long service life, which is 25 years or more and minimum maintenance during operation. However, the main drawback is the complex production and recycling, as well as solar cell panels contains toxic substances such as lead, cadmium, gallium, arsenic. Also one of disadvantages is a low coefficient of efficiency. The average value of this indicator is 12-25% in practice [21]. Its value depends on material used in the production of solar cell panels.

The main element is silicon. It does not take exposure to UV rays and it can only absorb infrared radiation. It reduces coefficient of efficiency. Therefore, one way of solar energy industry technical development is to create a multi-layer solar cell panel that can absorb all kinds of radiation. However, the amount of energy, which is obtained by means of the solar cell panel, can be increased not only by enhancing the efficiency and maximum spatial arrangement selection.

The potential amount of electricity generated by solar cell panels is estimated individually for each geographic location on Earth. Initial data for calculation is the amount of solar radiation and the nature of the cloud. Method does not consider the slope of surface, which absorbs solar radiation, and the presence of interfering objects. Therefore, the result is approximate.

The aim of this study is to increase the efficiency of solar cell panels in Tyumen by assessing the impact of spatial arrangement (geographic location), the climatic conditions and the presence of impeding objects on the amount of energy produced.

## **2. Equipment and devices used in studies**

The amount of electricity, which is generated by the solar cell panel, is determined with a multimeter. The solar cell panel is a photoelectric converter HH MONO-60W, which is a silicon single crystal panel. Its power is 60W, and the current is equal to 3.5A. The peculiarity of these solar cell panels is a high coefficient of efficiency which can reach 17-22% at ideal conditions. The electrical network also includes the battery (its voltage is 12V and its condensance is 100A·h) and charge controller (its voltage is 12/24V).

## **3. Results and discussion**

The amount of electricity that is generated by a solar cell panel depends on the amount of solar radiation coming onto its surface. Radiation from the sun spreads in all directions as electromagnetic waves. Passing through the layer of the atmosphere, the radiation is partly scattered, absorbed and reflected. This reduces the amount of solar radiation that reaches the earth's surface. Solar radiation depends on the geographical location and climatic conditions such as time of year, air temperature and humidity, cloudiness.

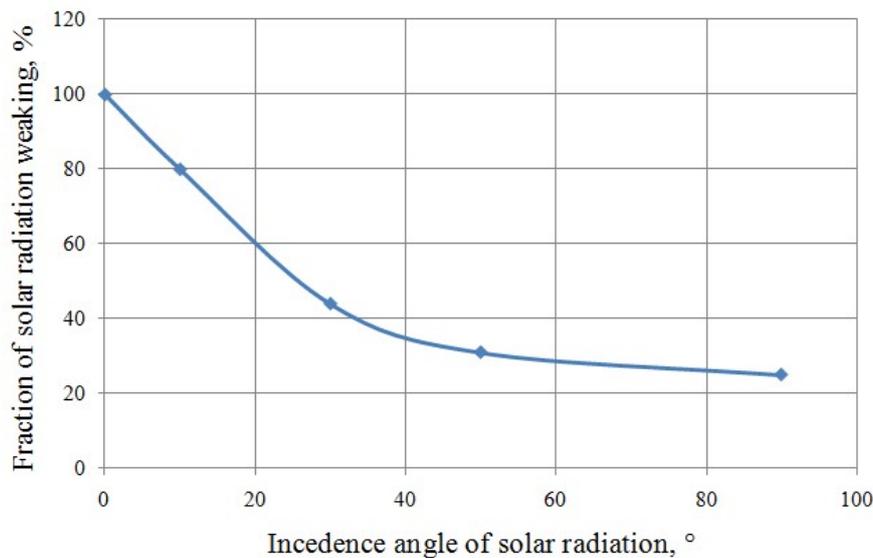
This paper describes the influence of solar cell panel spatial arrangement in different climatic conditions, as well as the existence of obstacles to change in the amount of electricity generated.

Solar radiation is distributed evenly on the surface, since the length of the path traveled by the rays in the atmosphere varies. Rays reach the shortest path the Earth's surface at the location of the sun at its zenith. This distribution of the rays occurs within latitudes 23° NL and 23° SL and is characterized by a small area of intensive energy transfer [22]. The angle of incidence decreases with increasing distance from this area, so the radiation propagates along a tangent line relative to the earth's surface and the area that receives the solar radiation increases. The amount of reflected energy is also rising. Dependence of the fraction of solar radiation weakening of the incidence angle is shown in Figure 1.

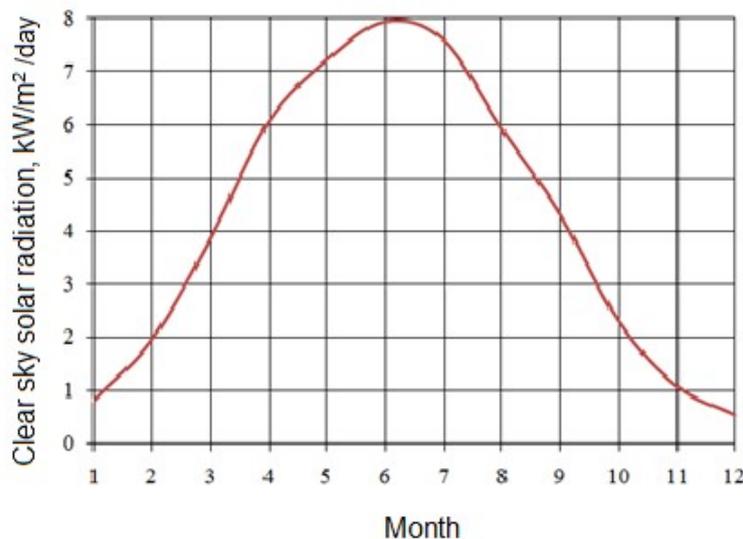
Reducing the angle of incidence of the rays increases the proportion of weakening rays therefore increasing the distance from the equator reduces the solar radiation that reaches the earth's surface. Dependence, which is represented in Figure 1, is one of the reasons for the low efficiency of solar cell panels in the Russian Federation in particular in Tyumen.

Geographical coordinates of Tyumen are  $65^\circ$  EL and  $57^\circ$  NL. In Tyumen solar radiation, which reaches the earth's surface, is shown in Figure 2.

Solar radiation of clear sky varies smoothly throughout the year. The form of this curve is close to the correct harmonic dependence [23]. This is because the radiation factors, which change periodically, and a set of local conditions. In the mid-latitude high and low total solar radiation corresponds to months with the minimum and maximum angle of sun declination (June, December). Thus, this work needs to be additional research that establishes the dependence of the angle of inclination of solar panels in Tyumen on the season, presence of impeding objects and weather conditions.

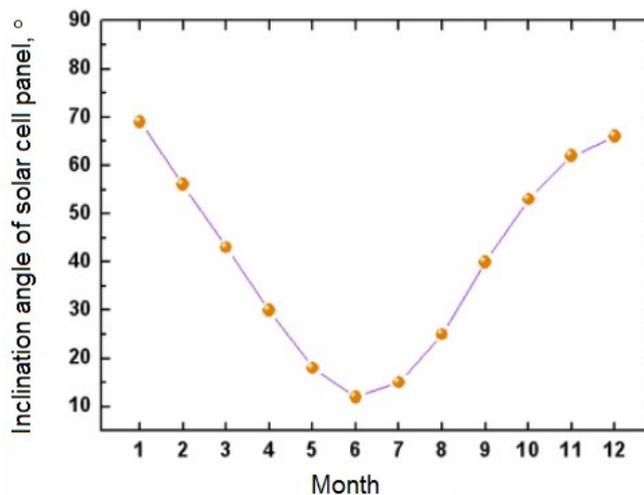


**Figure 1** – The dependence of the fraction of solar radiation weakening of the incidence angle



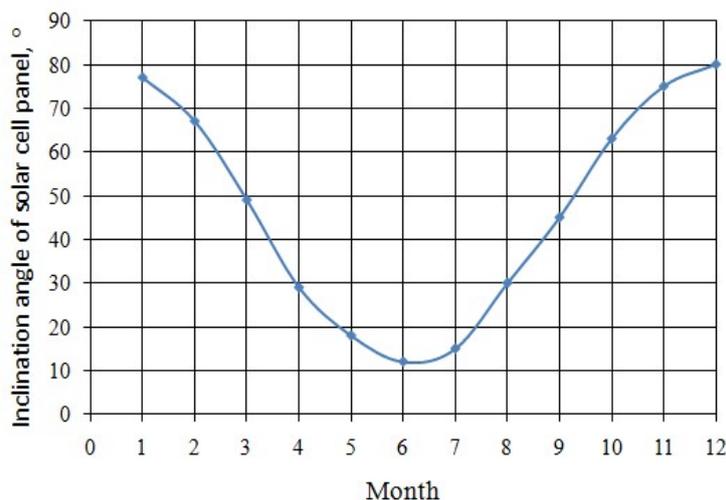
**Figure 2** – Changing of clear sky solar radiation in Tyumen during the year

Researches of Moldovan scientists describe a detailed methodology for calculating the inclination angle of the solar cell panel during the time of the year [24]. They share a total solar radiation into components such as direct, diffuse and back solar radiation from the surface. This approach allows you to get precise results. The study was conducted in Kishinev. Its geographical coordinates are 47° NL and 28° EL. The initial data of this calculation are the height and azimuth of the sun, the reflection coefficient of the ground, the amount of direct and diffuse radiation. The results are dependent changes in the inclination angle of solar cell panel of the month (Figure 3).



**Figure 3** – The dependence of inclination angel of solar cell panel on the month in Kishinev [24]

Calculations of optimum inclination angle of the solar cell panel in Tyumen were performed using a methodology, which is presented in the above study. The resulting dependence is shown in Figure 4.



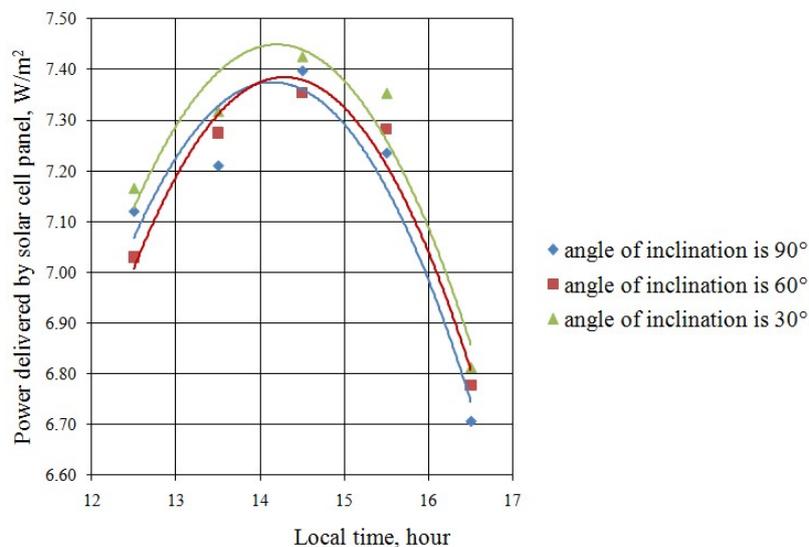
**Figure 4** – The dependence of inclination angel of solar cell panel on the month in Tyumen

The optimum inclination angle of solar cell panels, which is determined based on an analysis of theoretical data, ranges from 12 to 80 ° relative to the horizontal surface [25]. However, the theoretical calculation requires experimental confirmation.

The first stage of experimental research includes the study of the effect of air temperature, weather conditions, time of day and the presence of impeding objects on the amount of electricity that is

produced by a solar cell panel (power generated by a solar panel). Influence of the time of day on the amount of electricity produced by a solar cell panel that has a similar relationship with the change in the clear sky solar radiation throughout the year. It is shown in Figure 5.

The maximum amount of electricity generated is observed from 14:30 to 15:30, as the transparency of the air changes continuously throughout the day and it depends on the content of dust in the atmosphere, water vapor and other impurities. At noon, the atmosphere heats up as much as possible, so the amount of updraft is increased, and the proportion of solar radiation penetration is reduced. Afternoon heat emission into the atmosphere is reduced, so the amount of solar radiation, which reaches the surface of the solar cell panel, increases. This explains the increase in the amount of generated electricity.

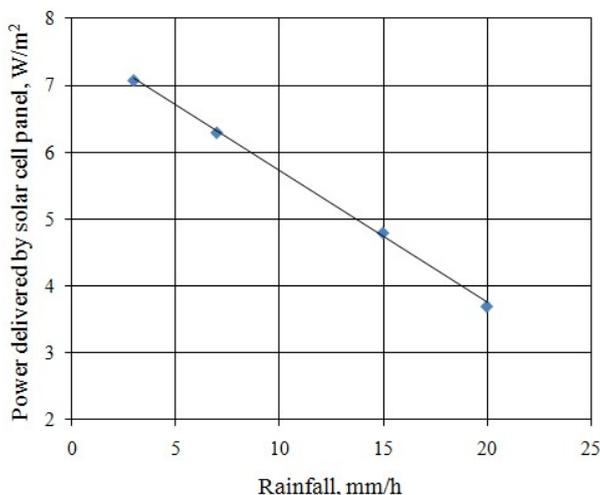


**Figure 5** – The dependence of the amount of electricity produced by a solar panel that is the time of day

In the atmosphere the amount of ascending currents depends on the ambient temperature. Rising temperatures increases the intensity of the mass heat exchange of the earth's surface and the air. It increases the amount of water vapor in the air, suspended solids, which prevent the spread of solar radiation. Thus, the air temperature increase reduces the amount of power that is generated by the solar cell panel.

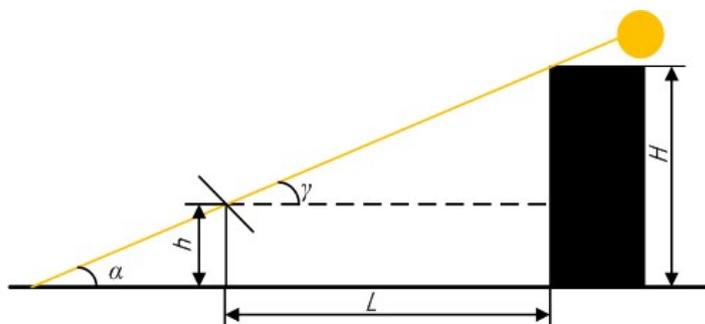
This study examines the impact of rainfall on the amount of power produced by the solar cell panel. This is shown in Figure 6.

The presence of water droplets in the air is an obstacle to the spread sun rays, so an increasing of rainfall decreases amount of solar radiation, hence it decreases the amount of electricity generated [26].



**Figure 6** – The dependence of the amount of electricity generated by the solar panel on rainfall

At the present time the increase in construction areas is an additional obstacle to the spread of direct sunlight [27]. The shaded areas are the areas of the earth's surfaces, which are mainly limited coverage or highlights daylight only for three hours. Shaded areas are determined by the duration of sunlight illumination and its intensity. In this case, the efficiency of the solar cell panels, which serve urban infrastructure, can be increased by performing the calculations and analysis scheme, which is presented in Figure 7.



**Figure 7** – Scheme of the spatial arrangement of the solar cell panel which serves the city infrastructure

The main condition, which ensures the supply of solar radiation on the panel surface, can be represented by the formulas:

$$\alpha > \gamma, \tag{1}$$

$$\gamma = \arctg(H-h/L), \tag{2}$$

Where  $H$  is height of the building, m;  $L$  is distance to the nearest high-rise building, m;  $h$  is support height, m;  $\alpha$  is the angular height of the sun, °;  $\gamma$  is the incidence angle of the rays on a solar panel, °.

This inequality will improve the efficiency of the solar panel, so as it will increase the surface area, which will be illuminated by direct sunlight.

#### 4. Conclusions

The first stage of the research establishes that the amount of solar radiation which enters the solar panel surface, as well as the amount of electricity generated depends on the time of day, air temperature, rainfall and the presence of impeding objects.

The increase of rainfall reduces the power generated by a solar panel. High-rise buildings are also an obstacle to the spread of direct sunlight. However, the optimum inclination angle of the solar cell panel can be calculated by analyzing the spatial position of the solar cell panels relative to the horizon and the surrounding high-rise buildings.

At the present time the changing of the inclination angle of the solar cell panel theoretically installed in Tyumen during the year. A further stage in this research will be obtained depending on the experimental confirmation, as well as it is developing recommendations for the installation of solar panels in urban infrastructure.

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